

Overview of Petroleum Refinery Types

Petroleum refineries are industrial complexes designed to convert crude oil into valuable products such as gasoline, diesel, jet fuel, lubricants, and petrochemicals. The complexity and configuration of a refinery depend on the type of crude oil being processed, the desired end-products, and market regulations. Refinery configurations range from simple distillation plants to highly complex facilities with advanced upgrading processes. Below is a detailed overview of the main types of petroleum refineries.

تمثل مصافي البترول مجمعات صناعية مصممة لتحويل النفط الخام إلى منتجات قيمة مثل البنزين، الديزل، وقود الطائرات، زيوت التشحيم، والبتروكيماويات. تعتمد تعقيد وتكوين المصفاة على نوع النفط الخام المعالج، والمنتجات النهائية المطلوبة، واللوائح السوقية. تتراوح تكوينات المصافي من وحدات التقطير البسيطة إلى المنشآت المعقدة التي تحتوي على عمليات متقدمة لتحسين جودة المنتجات. فيما يلي نظرة تفصيلية على الأنواع الرئيسية لمصافي البترول.

1. Atmospheric Distillation

The Crude Distillation Unit (CDU) is the first and most essential step in the refining process. It is also known as the topping unit or atmospheric distillation unit. The primary function of the atmospheric distillation tower is to separate crude oil into its components (or distillation cuts, distillation fractions) for further processing in other refining units. Due to the high flow rates handled by this unit, its size and operational costs are the largest in the refinery.

The capacity of the CDU ranges from 10,000 barrels per stream day (BPSD) to 400,000 BPSD, as larger units are favored in refinery economics. A moderately sized CDU can process around 200,000 BPSD.

Structure and Design of the Atmospheric Distillation Tower

- Height: These towers can reach 150 feet (50 meters).
- Fractionation Trays: They contain 20 to 40 trays, spaced at regular intervals, which help in separating different hydrocarbon fractions.

Operational Mechanism

Before entering the distillation column, desalted crude oil is preheated through a network of heat exchangers. This initial heating is done using hot material drawn from the bottom of the distillation tower, which raises the temperature of the crude oil to about 450°F.

After preheating, the crude oil is directed to a heating furnace, where its temperature is further increased to approximately 650°F.

Importance of Controlled Heating

Chapter 3

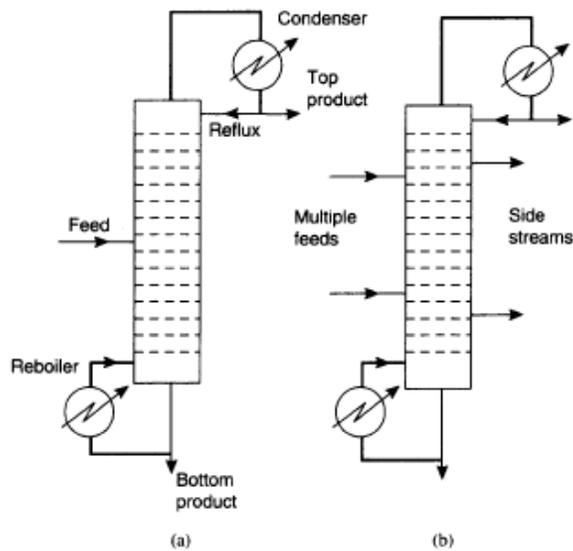
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This step is critical because carbon deposits may form inside the pipes and equipment when the oil is exposed to higher temperatures. Controlling the heating process prevents coke formation, which could cause blockages and reduce efficiency.

Evaporation and Fractionation Process

- The hot crude oil enters the distillation column, where most of it vaporizes.
- The lighter fractions rise to the upper sections of the column, while heavier fractions remain lower.
- The unvaporized heavy oil fractions and residues settle at the bottom of the column, where they are drawn off for further processing or use.

This step allows for the effective separation of hydrocarbons based on their boiling points, leading to the extraction of different refined products.



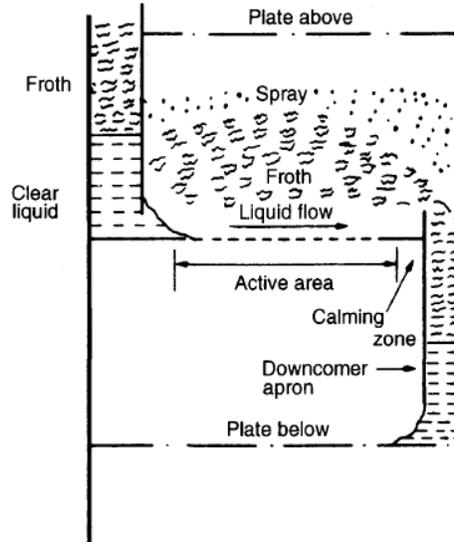


Figure 11.17. Typical cross-flow plate (sieve)

Fractionation Process and Its Key Factors

The efficiency of the fractionation process in a distillation column depends on three main factors:

1. Number of Trays – The more trays present in the column, the better the separation efficiency. Trays provide contact points between vapor and liquid, allowing multiple evaporation-condensation cycles to enhance fractionation.
2. Reflux Ratio – The reflux ratio is the proportion of the condensed overhead product that is returned to the top of the column. A higher reflux ratio leads to better separation as it allows for more contact between rising vapors and returning liquid, improving purity.
3. Quantity of Steam Added to the Column – The injection of steam into the column helps reduce the partial pressure of hydrocarbons, enhancing the separation of lighter components. It also prevents thermal cracking of heavier fractions.

Effect of Increasing Trays and Reflux Ratio

As the number of trays and the reflux ratio increase, the separation efficiency improves, resulting in better product purity and yield.

Key Processing Units:

- Atmospheric Distillation Unit (ADU): Separates crude into naphtha, kerosene, diesel, and atmospheric residue.
- Products: Naphtha (used for blending or as a feedstock for petrochemicals)
- Kerosene (used as a fuel or further processed)
- Diesel
- Residue (typically used for fuel oil)

Limitations:

- Does not have secondary processing units for improving fuel quality.
- Produces a high percentage of residual fuel oil, which has low market value.
- Cannot process heavy, sour crude efficiently.

Common Applications:

- Typically found in oil-producing regions to supply local fuel needs or as a pre-treatment stage before sending intermediate products to more advanced refineries

2. Vacuum Distillation Column

The residue from an atmospheric distillation tower can be further processed in a vacuum distillation tower, which allows for the recovery of additional liquid fractions.

Under atmospheric pressure, the temperature required to distill heavier fractions of crude oil is so high that thermal cracking would occur, leading to the formation of undesirable by-products. To prevent this, these heavier fractions are distilled under vacuum conditions, where the boiling temperature is reduced as pressure decreases.

Role of Steam Addition

- Steam is added to the furnace inlet, which increases tube velocity and prevents coke formation in the furnace.
- Steam also lowers the total hydrocarbon partial pressure inside the vacuum tower, enhancing the separation process.

Main Products from the Vacuum Distillation Unit

1. Heavy Gas Oil
2. Lubricants
3. Asphalt or Vacuum Residue (Boiling Point > 1000°F)

This vacuum distillation process maximizes yield from crude oil while minimizing waste and undesirable by-products.

Cracking in Petroleum Refining

Cracking refers to the thermal decomposition of high-boiling petroleum fractions, such as heavy fuel oil, at high temperature and pressure to produce lower-boiling, lighter hydrocarbons. It is an endothermic reaction that requires energy input.

The cracking process increases the yield of lighter hydrocarbons by breaking carbon-carbon bonds, leading to the formation of various useful petroleum products.

Types of Cracking

1. Thermal Cracking – Cracking that occurs at high temperatures without the presence of a catalyst.
 - Examples: Visbreaking, Delayed Coking, Fluid Coking.
2. Catalytic Cracking – Cracking that occurs in the presence of a catalyst, reducing the energy required for breaking molecular bonds.
 - Examples: Fluid Catalytic Cracking (FCC), Hydrocracking, Deep Catalytic Cracking (DCC).

1. Thermal Cracking

Thermal cracking involves breaking down large hydrocarbon molecules by exposing them to high temperatures and pressures.

Classes of Industrial Thermal Cracking**a. Visbreaking**

Visbreaking is a mild thermal cracking process, where moderate heating is applied to partially break heavy oil residues. This reduces the viscosity of the feedstock and produces some light hydrocarbons.

- Feedstocks:
 - Atmospheric Residue (AR)
 - Vacuum Residue (VR)

This process helps in reducing the need for blending diluents and increases the production of usable liquid fuels.

b. Delayed Coking

Delayed coking is a thermal cracking process that converts heavy residues into lighter products, while leaving behind solid coke as a by-product.

Feedstocks:

- Vacuum Residue
- Cracked Residue

Main Products:

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- Gases (Light hydrocarbons)
- Naphtha
- Fuel Oil
- Gas Oil
- Coke

Process Overview:

A schematic flow diagram of the delayed coking process typically includes:

- Furnace
- Two Coke Drums
- Fractionator

1. Feed Processing

- Residual oil from the vacuum distillation unit is pumped into the bottom of the fractionator.
- The oil is mixed with injected steam to prevent coke buildup in the furnace tubes.
- The mixture is then heated in the furnace to about 480°C (896°F).

2. Coking Drums & Cracking Reaction

- The liquid-vapor mixture exits the furnace and enters one of the coke drums.
- Thermal cracking occurs in the drum, converting heavy fractions into lighter hydrocarbons, while solid coke deposits inside the drum.
- The coking process takes approximately 24 hours per drum.

3. Drum Switching & Coke Removal

- Once the first drum is full of solid coke, the hot mixture is redirected to the second drum.
- The filled drum is purged with steam to remove remaining hydrocarbons and then quenched with water to cool down the coke.
- Vapors from the top of the coke drum are sent back to the fractionator, where steam and thermal cracking products (gas, naphtha, and gas oils) are separated.

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- The top and bottom sections of the coke drum are removed, and the solid coke is cut out using high-pressure water nozzles.
- The coke then falls into a pit, pad, or sluiceway for reclamation and storage.

Key Advantages of Delayed Coking:

- Converts low-value residues into higher-value liquid fuels.
- Produces solid petroleum coke, which can be used in metallurgical and industrial applications.
- Prevents thermal cracking inside the furnace by separating the cracking reaction into coke drums.

Delayed coking is one of the most widely used processes in refineries for handling heavy residues while maximizing fuel production

c. Fluid Coking and Flexi Coking

The third coking process involves severe thermal cracking, making it more advanced than delayed coking.

Flexi Coking – A Highly Efficient Process

- Flexi coking is one of the most important processes in modern refineries.
- Unlike delayed coking, only 2% of coke is produced from the residual feedstock, meaning higher conversion efficiency.

Process Characteristics

- Continuous Operation: Unlike delayed coking, which operates in batch mode, fluid and flexi coking are continuous processes.
- Thermal Cracking in a Fluidized Bed:
 - The process occurs in a fluidized coke bed, where residual oil is thermally cracked into lighter hydrocarbons.
 - The remaining coke particles stay suspended in the fluidized bed, avoiding excessive solid buildup.
- Coke Gasification:
 - Instead of discarding solid coke, flexi coking partially gasifies the coke at 870°C.

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- This reduces waste and produces valuable synthesis gas (syngas), which can be used as fuel in refinery operations.

Key Advantages of Flexi Coking:

- Minimizes coke production (only 2% residual coke).
- Higher liquid fuel yield compared to delayed coking.
- Gasifies coke to produce syngas, improving refinery energy efficiency.
- Continuous operation reduces downtime and improves efficiency.

Flexi coking is a superior process in refineries looking to maximize liquid product yield while minimizing waste coke production.

2. Catalytic Cracking

Catalytic cracking is a process in which higher hydrocarbons are broken down at lower temperatures (350-650°C) and lower pressure (2 atm) using a catalyst. This process improves the quality of gasoline by producing higher octane fuels.

Feedstocks for Catalytic Cracking:

- Gas oil
- Heavy crude oil
- Residuum (residue from vacuum distillation)

Catalysts Used:

- Zeolites (modern catalysts)
- Metals such as platinum, nickel, and iron silica-alumina

Advantages of Catalytic Cracking Over Thermal Cracking:

- ✓ Lower temperature and pressure requirements reduce energy consumption.
- ✓ Higher yield and octane number improve fuel quality.
- ✓ Lower gum and gum-forming materials in the final gasoline product.
- ✓ Reduced sulfur content for cleaner fuels.
- ✓ Higher aromatic content enhances anti-knock properties of gasoline.

Reforming Process

What is Reforming?

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Reforming is a process that rearranges molecular structures to produce high-octane gasoline (reformate) from low-octane naphtha. It does not significantly alter the molecular weight of the feedstock.

Feed for Reforming:

- Naphtha from straight-run distillation
- Naphtha from catalytic cracking and coking
- Best results are obtained from straight-run naphtha with high naphthene content

Reforming Products:

- Reformate (high-octane gasoline)
- Lighter hydrocarbons (gases)
- Hydrogen (used in hydro processing)

Types of Reforming

Reforming can be classified into two types, similar to cracking:

1. Thermal Reforming

- Performed without a catalyst, similar to high-temperature, low-pressure thermal cracking.
- Feedstock: Primarily naphtha.
- Products:
 - Gasoline (75-80%) with an octane number of 81-86.
 - Gas (13-14%).
 - Polymers (unwanted gum) and losses.
- Disadvantage: Almost completely replaced by catalytic reforming due to inefficiency.

2. Catalytic Reforming

- Conducted in the presence of a catalyst.
- Advantages Over Thermal Reforming:
 - Higher efficiency and product selectivity.
 - Higher hydrogen production, useful in hydroprocessing.

Types of Catalysts Used in Catalytic Reforming:

- ✓ Non-Precious Metal Oxides – Example: Molybdenum or Chromia on alumina.
- ✓ Precious Metal Oxides – Example: Platinum on silica-alumina or alumina base (most selective catalyst).

Significance of Reforming in Refining

- Enhances gasoline quality by increasing octane numbers.

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- Produces valuable hydrogen for other refining processes.
- Improves fuel properties, reducing unwanted gum and increasing stability.

Catalytic reforming is a critical refining process used to produce high-quality gasoline and provide hydrogen for hydroprocessing.